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BALANCE OF PERFORMANCE PARAMETERS FOR SURVIVABILITY AND MOBILITY IN THE DEMONSTRATOR FOR NOVEL DESIGN (DFND) VEHICLE CONCEPTS

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ABSTRACT

This paper addresses the balance of performance parameters of occupant survivability and vehicle mobility during trade study analysis and simulation for the TARDEC Demonstrator for Novel Design (DFND) vehicle concepts. Occupant survivability and vehicle mobility are often competing attributes in the design of current armor protected tactical and combat ground vehicles. Increased armor weight and high stand-off height parameters are favorable for occupant survivability during underbelly blast events but are detrimental to vehicle dynamics mobility performance. TARDEC and Pratt & Miller Engineering are implementing a motorsports based design process and simulation approach using a holistic systems engineering trade study to develop potential concepts that maximize force protection, vehicle mobility, and vehicle survivability. A number of specialized simulation tools including hypervelocity explicit finite element analysis and multi-body simulation are used interactively to provide accurate representations of blast and mobility events.

INTRODUCTION

Occupant survivability and vehicle mobility are often competing attributes in the design of current armor protected tactical and combat ground vehicles. Increased armor weight and high stand-off height parameters are favorable for occupant survivability during underbelly blast events, but are detrimental to vehicle dynamics mobility performance. During the development of vehicle concepts, competing parameters such as stand-off height and vehicle handling can be evaluated for performance using simulations for blast and mobility and for packaging using computer aided design. The results from these simulations and other vehicle design parameters are included in a holistic systems engineering trade study. This paper describes the motorsports-derived design and simulation process used by Pratt & Miller Engineering and the U.S. Army Tank and Automotive Research, Development, and Engineering Center (TARDEC) to guide the development of Demonstrator for Novel Design (DFND) vehicle concepts.

Demonstrator for Novel Design (DFND) Program Description

The Demonstrator for Novel Design (DFND) program is a TARDEC sponsored effort to develop novel vehicle concepts for a medium combat vehicle with the primary objectives of maximizing force protection, vehicle mobility, and vehicle survivability. Pratt & Miller Engineering is applying its lean product development process, refined during 21 years of success in the professional motorsports industry, to develop DFND vehicle concepts on a compressed timeline. An occupant-centric design approach is being utilized in order to protect the soldier. The safety technologies and design practices used to protect race drivers are being incorporated into the DFND vehicle concepts. The DFND wheeled vehicle concepts are designed to carry a 3 man crew with 10 dismounts at a weight of 40,000 lb. – 60,000 lb. A key feature of the motorsports lean product development process and innovation best practices is to keep the design space as wide as possible at the beginning of the concept development

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phase. This paper focuses on the systems engineering trade study process used to compare the vehicle concepts for force protection, vehicle mobility, and vehicle survivability.

REQUIREMENT DEFINITION

The requirements for the DFND vehicle were identified to guide the overall performance and package of the concepts. Since the objective of this effort was to develop novel concepts, a small subset of typical medium combat vehicle requirements was applied. The requirements were divided into performance requirements and packaging requirements. The performance requirements included those that were simulated to assess the concept performance to targets. The packaging requirements included those that were used to make space and weight claims in the concept package. All requirements in the subset applied to primary the DFND program objectives of maximizing force protection, vehicle mobility, and vehicle survivability.

Force Protection Requirements

The force protection requirements for the DFND concept development focused on the underbelly blast event. Other types of threats were considered in the vehicle concepts for packaging space claim and weight, but not simulated in this effort. The vehicle package and systems engineering followed an occupant-centric design approach to apply safety technology and methodology from the professional motorsports industry to the vehicle concepts. Evaluation of occupant injury criteria was beyond the scope of the concept development. For this study, the force protection performance was evaluated based on reducing hull vertical acceleration (Az). The threshold or objective targets were not specified in the requirements, so a range was set that included the vertical acceleration values simulated as shown in Table 1.

Requirement	Threshold	Objective
Underbelly Blast Hull Mass Vertical Acceleration	Not specified – set at 200 g	Not specified – set at 140 g

Table 1: Force Protection Requirements

Vehicle Mobility Requirements

The mobility requirements for the DFND concept development included several events used to characterize the ride, handling, and obstacle performance of the concepts. The total list of mobility calculations and simulations performed to evaluate the concepts included:

1. Static stability factor
2. Lateral stability
3. NATO lane change
4. Half rounds
5. RMS roads
6. Gap crossing
7. Step climb
8. Static side slope
9. Side slope maneuver
10. V ditch
11. Top speed
12. Speed on grade
13. 60% Grade climb
14. Ground contact pressure
15. Tractive effort
16. Turning radius

Threshold and objective targets were set for each event. For this study, the static stability factor, half round event, and vertical step climb were used to compare the ride and handling performance of the proposed vehicle concepts. The threshold and objective targets are shown in Table 2.

Requirement	Threshold	Objective
Static Stability Factor	Not specified – set at 0.6	Not specified – set at 0.9
12” Half Round	Not specified – set at no more than 2.5g at 12 MPH	Not specified – set at no more than 2.5g at 20 MPH
Vertical Step Climb	24”	36”

Table 2: Mobility Requirements

Vehicle Survivability Requirements

For the purposes of the DFND vehicle concept development, vehicle survivability is defined as the ability of the vehicle to remain mobile after an underbelly blast event. The systems considered in assessing the vehicle survivability for this study included the power pack and the power delivery to the wheels. There were no specific vehicle survivability requirements provided, but enablers were considered throughout the concept development. The specifications and selection for the power pack and power delivery to the wheels was based on meeting the vehicle performance requirements for mobility. Concurrently, an assessment of the system vulnerability was performed based on physical packaging to rank the vehicle survivability.

Requirement	Threshold	Objective
Number of Power Packs	Not specified – set at 1	Not specified – set at 3
Number of Power Delivery Paths	Not specified – set at 1	Not specified – set at 10

Table 3: Vehicle Survivability Requirements

Packaging Requirements

The packaging requirements used for the DFND concept development were derived from vehicle requirements. The vehicle requirements included items such as accommodating the 95th percentile soldier, a 3 man crew, and 10 dismount soldiers. Since this was an initial concept development effort, the detailed design of every system was not completed. All major systems and requirements were considered and space and weight claims were made for electronics, power generation, armor, cooling, exhaust, air conditioning, government furnished equipment, and others based on the vehicle requirements. For this study, the primary packaging related parameters were center of gravity (CG) height, number of power packs, and number of power delivery paths.

Competing Requirements and Design Parameters

Typically, detailed design, simulation, and analysis is required to populate a detailed trade study and make final specification decisions. Applying the trade study process to the development of concepts requires a simple, flexible, and expandable format that can be modified as additional data is generated. This paper describes an example of the concept trade study process being used by Pratt & Miller Engineering and TARDEC on the DFND program. In order to describe the process, a simplified performance parameter set is used in the paper. This study focuses on the process used to balance the performance of force protection, vehicle mobility, and vehicle survivability by exploring the interaction of six primary vehicle design parameters. While there are thousands of vehicle design parameters that influence the detailed design of a medium combat vehicle, the six shown in Table 4 were chosen to quantify the primary objectives of the DFND program and demonstrate the trade study process.

Parameter	Description
CG Height	Vertical distance from the ground to the vehicle center of gravity
Track Width	Cross vehicle width between wheel centerlines
Stand-off Height	Vertical distance from the ground to the lowest structural member of the hull
Wheel Travel in Jounce	Vertical suspension travel in jounce (compression of suspension)
Power Pack	Drive power source
Driveline	Components that transmit power from the power pack to the wheels

Table 4: Design Parameters

These six design parameters were used to compare different vehicle concepts. Table 5 illustrates the competing nature of the selected design parameters. These rankings are directional only and performed by subject matter experts. Each row indicates a direction of change in the primary design parameter. The three columns represent the primary DFND program objectives. A positive symbol (+) indicates an improvement in that objective, a negative symbol (-) indicates degradation in that objective, and a zero (0) indicates that there is no change or not enough information to predict the directional change. For example, a higher stand-off height will reduce the acceleration on the hull from an underbelly blast, but increases the probability of vehicle rollover. Also, increased suspension travel in jounce can improve the vehicle ride, but requires additional packaging space that can drive the CG height of the vehicle higher.

	Force Protection	Vehicle Mobility	Vehicle Survivability
Higher CG height	+	-	+
Wider Track Width	0	+	0
Higher Stand-off Height	+	-	+
More Wheel Travel in Jounce	0	+	0
Higher Number of Power Packs	0	0	+
Higher Number of Power Delivery Paths	0	+	+

Table 5: Competing Design Parameters

Simulations for blast performance, mobility performance and vehicle packaging were completed using ranges of vehicle design parameters. Each simulation produced many responses that were indications of performance of the design parameters. The primary performance parameters shown in Table 6 were identified to quantify the performance of the concepts.

Performance Parameter	Objective	Description
Az Center Blast	Force Protection	Vertical acceleration of hull mass from a center underbelly blast
Static Stability Factor	Vehicle Mobility	Track width / (2 x CG height)
2.5g Speed over 12" Half Round	Vehicle Mobility	Speed at which vertical acceleration of driver is 2.5g over 12" half round
Height of Vertical Step Climb	Vehicle Mobility	Height of vertical wall that can be climbed by the vehicle
Number of Power Packs	Vehicle Survivability	Number of power pack sets in vehicle
Number of Power Delivery Paths	Vehicle Survivability	Number of paths that deliver torque to the wheel stations

Table 6: Performance Parameters

The performance parameter values from the simulations were combined into a trade study to rank the vehicle concepts based on the performance parameters.

THE TRADE STUDY PROCESS

A critical element of Lean Product Development and the Systems Engineering process is a robust trade study methodology. As concepts are developed and designs evaluated against competing requirements, systems engineers need a consistent, reliable, and efficient decision-making process that allows them to balance performance, reliability, cost, and schedule. This decision-making process must be used across all system domains and be implemented during initial concept selection through final component design specification. The trade study process is shown in Figure 1.

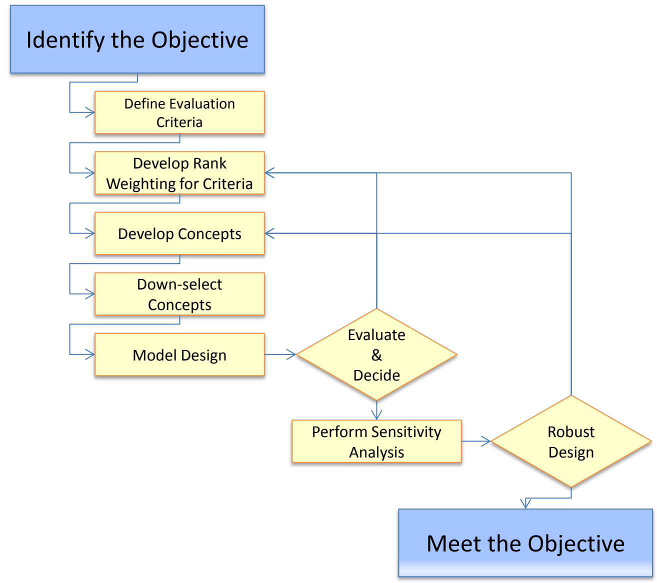

Figure 1: DFND Trade Study Process

The concept down-selection process uses Pugh's Method of Controlled Convergence where many vehicle and system concepts are scored against criteria relative to a baseline concept (often a best-in-class benchmark)[1]. The scoring is a simple plus, same, minus ranking that allows quick evaluation of a large number of concepts (see Table 7).

Criteria (Design Objectives) \ Design Alternatives	1 (BASELINE)	2	3	4	5
Az Center Blast	S	-	S	-	+
Static Stability Factor	S	-	-	+	+
2.5G Speed over 12" Half Round	S	-	S	-	-
Height of Vertical Step Climb	S	S	+	S	+
Number of Power Packs	S	S	+	+	S
Number of Power Delivery Paths	S	S	+	S	-
Total +'s	0	0	3	2	3
Total S's	6	3	2	2	1
Total -'s	0	3	1	2	2

Legend	
+	Significantly Better
S	About the Same
-	Significantly Worse

Table 7: Notional DFND Concept Down-Selection Matrix

Once the large candidate set of concepts is down-selected for more detailed model based analysis, a detailed trade hierarchy is constructed according to the vehicle requirement objectives. These objectives are cascaded to a series of design criteria and n^{th} order sub-criteria as defined by the system architecture as illustrated in Figure 2.

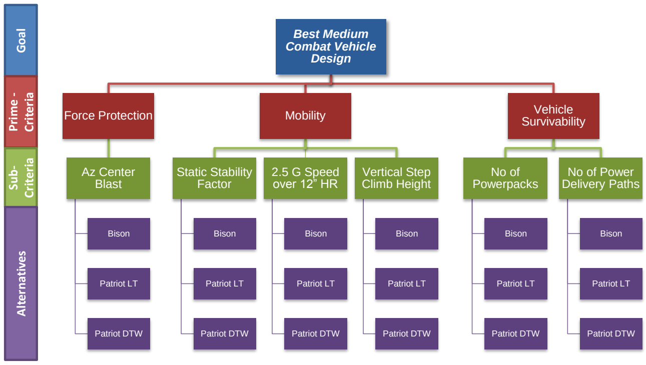

Figure 2: DFND Trade Hierarchy Example

The next step in the process involves assigning weighting factors to each of the criteria to determine its importance and rank relative to all design objectives. This is a critical step as it determines the relationship between requirements and design specifications and provides the system cascade mapping to assess how each change in specification will affect the overall requirements. Because of the highly complex systems and competing parameters involved in combat vehicle design, Pratt & Miller Engineering uses the Analytical Hierarchy Process (AHP) to set the weighting factors for each criteria [2]. The AHP method is used regularly in the aerospace industry and is the standard ranking method used by the FAA and NASA.

First, the global weighting of the Level 1 criteria is performed according to practices of AHP as shown in Table 8. This is achieved by making a pair-wise comparison of each criteria according to the Scale of Relative Importance as shown in Table 9.

LEVEL 1 CRITERIA - Global Weighting

	Force Protection	Mobility	Survivability	Nth root of Product	Global Weighting
Force Protection	1	1.5	2	1.44	45%
Mobility	0.67	1	2	1.10	35%
Survivability	0.50	0.50	1	0.63	20%

Table 8: Level 1 Criteria Global Weighting

A global weighting is generated and will be used in subsequent analysis to evaluate design trades.

Scale of Relative Importance		
Intensity of Importance	Definition	Explanation
1	Equal Importance	Two parameters contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one over the other
5	Strong Importance	Experience and judgment strongly favor one over the other
7	Very Strong Importance	One objective is favored very strongly over the other; its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one objective over the other is of the highest possible order of affirmation
Intensities of 2,4,6,8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for objectives that are very close in importance.		

Table 9: Scale of Relative Importance

This process is duplicated for each of the sub-level criteria to create a local weighting for every design objective. Once local weightings are established and verified for each criteria, its corresponding global weighting is calculated as:

$$GWF_{(\text{level } n)} = LWF_{(\text{level } n)} * LWF_{(\text{level } n-1)}$$

Where:
LWF(level n) = local weighting factor of the child sub-level n criteria
LWF(level n-1) = local weighting factor of the parent level n-1 criteria

Once this has been completed for all criteria, the rank importance of all criteria can be evaluated and confirmed (see Figure 3).

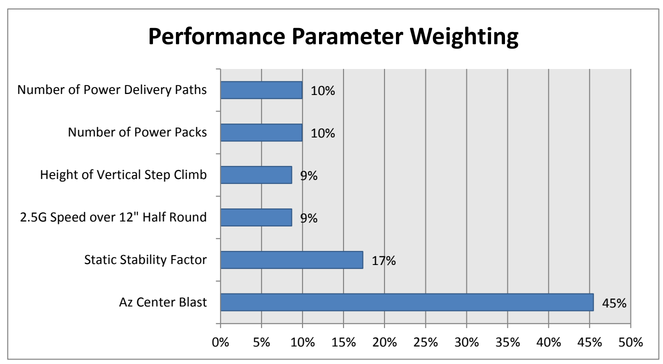

Figure 3: Performance Parameter Weight Ranking

The framework is now complete to populate the trade matrix with design parameter metrics. To properly evaluate the complete system performance of alternatives and conduct trade analysis, the design parameter metrics must be 'normalized' to a non-dimensional scale. This is most commonly done through the use of Utility Functions or Utility Curves [3]. Parameter values for threshold and goal are established and the function or curve is developed between the value of 0 and 1. The function can be continuous, discrete or binary in its behavior as illustrated in Figure 4.

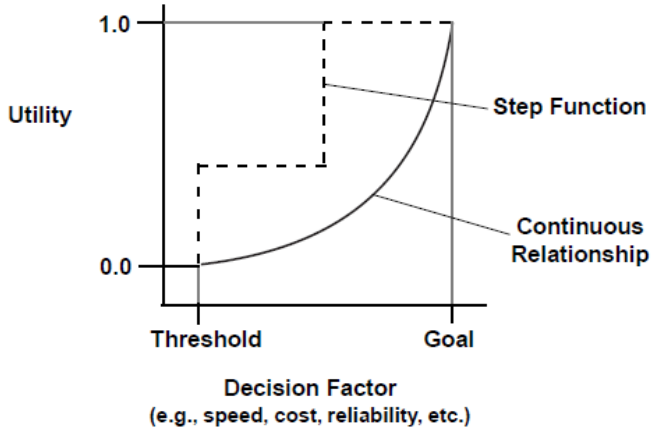

Figure 4: Example Utility Curves

For the DFND trade analysis, metrics from force protection, mobility, and vehicle survivability were generated from model based simulation and utility curves generated to normalize them from 0 to 1. The sum of the products of the parameter weighting factors and normalized measures are evaluated to generate a score providing a ranking of total system performance for each concept. Optimized system performance would receive a score of 1 indicating that each parameter's goal was achieved. This can also be visualized using a spider chart.

Trade Study Matrix

		OPTIONS		
Requirements	**Weighting**	**CONCEPT 1**	**CONCEPT 2**	**CONCEPT 3**
Payload	0.05	0.5	1.0	0.7
Maneuverability	0.10	0.7	0.8	0.9
Weight	0.10	1.0	0.7	1.0
Mobility	0.25	0.8	0.9	0.3
Occupant Survivability	0.30	0.6	1.0	0.7
Vehicle Survivability	0.20	0.5	0.8	1.0
Total	100%	0.68	0.89	0.71

Table 10: Trade Study Concept Scoring

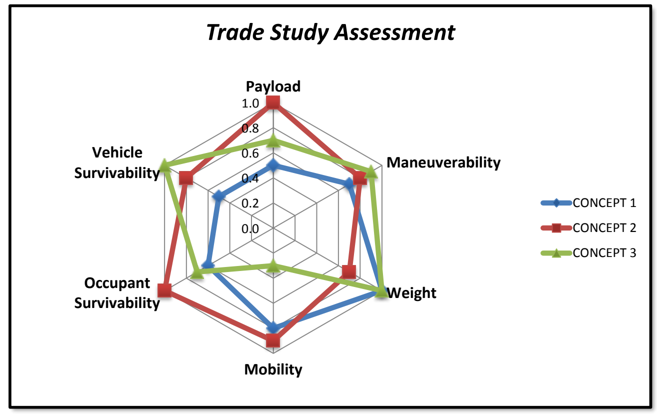

Figure 5: Trade Study Concept Spider Chart

The final step in the trade study process is to perform a sensitivity analysis on the parameters to understand the sensitivity to weighting factors on the overall scoring of concepts. Each parameter weighting is perturbed to assess the magnitude and ranking of measure scores. The same sensitivity analysis is performed on the utility functions of each parameter to understand the effect on overall concept score. This last step also serves to validate the alignment of parameter measure, parameter ranking, and system hierarchy to the overall customer or program needs. Once this has been agreed upon by the system integrators, a robust trade analysis can be efficiently and robustly performed throughout the concept and design process.

CONCEPT DESCRIPTION

The concept down-selection process shown in Table 7 was used to reduce thousands of potential vehicle concepts to three primary DFND vehicle concepts. The basic description of the design parameters for the primary vehicle concepts is provided in Table 11. The names of Bison, Patriot Leading Trailing (LT), and Patriot Dynamic Track Width (DTW) were assigned to the three selected concepts.

Design Parameter	Bison	Patriot LT	Patriot DTW
CG Height	68.5"	60.8"	60.8"
Track Width	94"	94"	106"
Stand-off Height	20.5"	26"	26"
Wheel Travel in Jounce	8"	8"	12"
Power pack	Single	Dual	Dual
Driveline	Conventional	Electric hub motors	Electric hub motors

Table 11: DFND Concept Design Specifications

SIMULATION PROCESS

The blast simulations, mobility simulations, and vehicle packaging results were used to quantify the performance parameters of the DFND vehicle concepts. Each simulation process began with an exploration of the design space by varying the design parameters. This information was used to develop individual vehicle concepts by combining the attributes into potential vehicle packages considering performance and space claims. These vehicle concepts were then simulated as full vehicle systems. The results of these full vehicle simulations were combined into the trade study. This section will describe the simulation tools, the simulations performed, and the results.

Blast Simulation

The blast simulations for the vehicle concepts were performed using Velodyne. Velodyne is a proprietary software package developed by the Corvid Technologies subsidiary of Pratt & Miller Engineering. Velodyne [4] is a fully coupled, multi-physics, hydro-structural solver used to simulate complex high strain rate events. During the DFND concept development, the simulations were focused on underbelly blasts. Studies were performed to identify trends for hull shape, hull thickness, vehicle weight, stand-off height, wheel well shape, and wheel location. The results of these studies were used to guide the development of the full vehicle concepts. For this study, the results for vertical acceleration at a center blast location were compared between the three primary vehicle concepts.

For the initial stand-off height comparisons, a simplified hull structure was used as shown in Figure 6 below. The blast model was set up using a consistent charge size and soil depth [5]. The vehicle mass was set to match the status of the sprung hull mass system not including the tires, wheels, and wheel end assembly mass. The hull was simulated at stand-off heights of 18”, 29” and 40”.

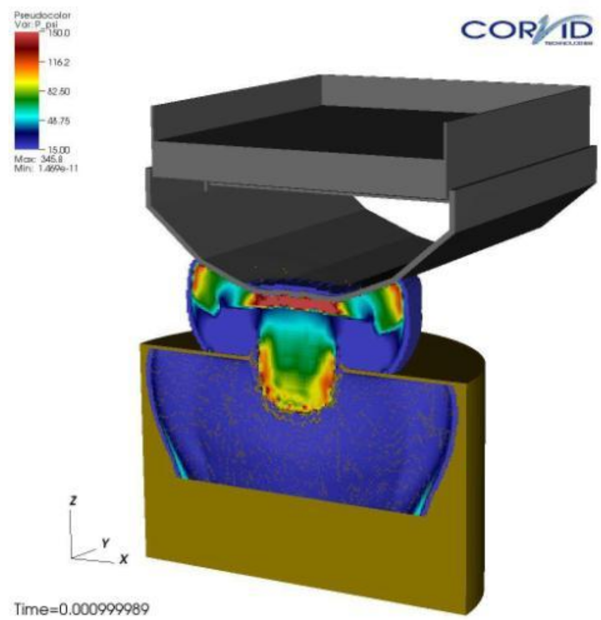

Figure 6: DFND Hull Blast Simulation

The vertical acceleration (g) vs. time (ms) is shown in the Figure 7 and is plotted in Figure 8 to show the peak acceleration (g) vs. stand-off height (in). This trend study was used to quantify the reduction in hull acceleration with increased stand-off height and is plotted in Figure 9.

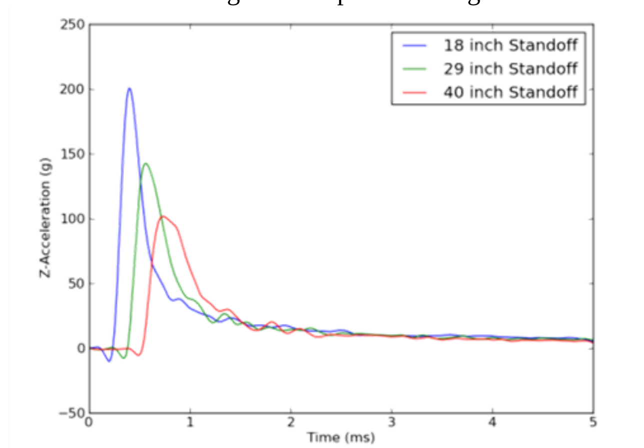

Figure 7: Vertical Acceleration vs. Time for Stand-off Height Simulations

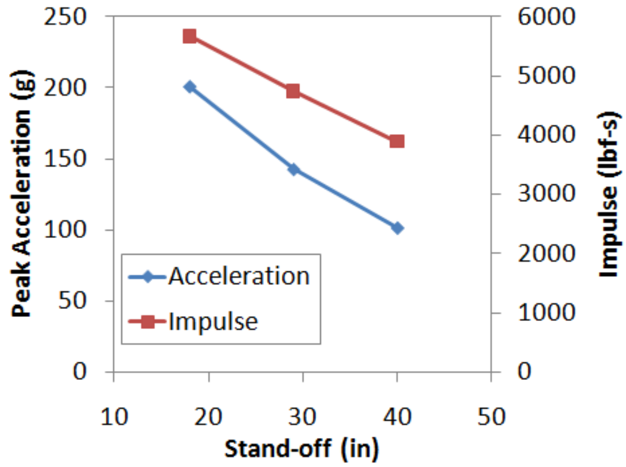

Figure 8: Peak Acceleration vs. Stand-off Height

The blast simulation results were used to guide the development of full vehicle concepts. Many performance parameters were measured, but for the purpose of this study, vertical acceleration was chosen as the primary performance parameter. Once packaging for the three primary vehicle concepts was developed and the design specifications identified, the vertical acceleration values (Az) for a centered blast were approximated as shown in Table 12.

	Bison	Patriot LT	Patriot DTW
Az for center blast	187 g	158 g	158 g

Table 12: Blast Simulation Results

These concept blast simulations did not include all of the under hull systems. The interactions of these systems are considered in other rankings as described in the trade study. The purpose of this initial blast modeling was to quantify the effect of stand-off height on vertical acceleration and include this data in the full vehicle trade study. Additional studies would be required to include all of the under hull systems and look at the performance difference from the track width increase from the Patriot LT to the Patriot DTW.

Mobility Simulation

The DFND concept development mobility simulation included many events as listed in the mobility requirement definition section. For this study, the static stability factor, half round event, and step climb event results were included in the trade study process example.

The static stability factor is a basic indication of the roll over resistance of the vehicle concepts based on the vehicle dimensions.

Static stability factor [6] is defined as:

$$SSF = T / (2H)$$

Where:

T = track width defined as the cross-car vehicle width between wheel centerlines

H = CG height defined as the vertical distance from the ground to the center of gravity height of the vehicle

The inputs and results of the static stability factor calculations are shown below. A higher static stability factor is an indication of a more stable vehicle platform. Higher numbers can be achieved through lowering the CG height and/or increasing the track width. Through a lower CG height and a wider track width, the Patriot DTW achieves the highest static stability factor.

	Bison	Patriot LT	Patriot DTW
Track Width	94”	94”	106”
CG Height	68.5”	60.8”	60.8”
Static Stability Factor	0.69	0.77	0.87

Table 13: Static Stability Factor

The dynamic mobility simulations were performed using MSC.ADAMS (Automatic Dynamic Analysis of Mechanical Systems) multi-body dynamics software. ADAMS incorporates real physics by simultaneously solving all equations of motion, allowing for the dynamic analysis of non-linear mechanical systems with accurate computation of loads and forces as they vary throughout the full range of operation. Specifically, the ADAMS/Car module, version 2011, was used for all model creation, analysis and results post-processing [7]. ADAMS/Car is a customized version of ADAMS, allowing the user to readily create detailed automotive modeling elements and perform automotive specific analyses. An ADAMS vehicle model was constructed for each of the three primary DFND concept vehicles.

Several half round sizes were simulated based on the vehicle requirements with the objective of not exceeding 2.5g at any occupant position at a target speed. The simulation was set-up to match the physical test operating procedure for ride dynamics TOP 1-1-014 [8]. The suspension tuning has an impact on the performance of the vehicle, so a basic damping and spring rate sweep was performed to establish the trends. The full tuning and optimization of the suspension parameters is not justified for concept development, but must be considered due to the impact on vehicle performance. The plot of driver acceleration vs. speed for the three concepts over the 12” half round is shown in Figure 9. The threshold target was set at 12 miles per hour (MPH) and the objective at 20 MPH. The Patriot LT does not meet the threshold target by reaching the 2.5g limit at 10.3 MPH. The Bison performs the best at 19.4 MPH and the Patriot DTW achieves 13.9 MPH. It is important to recognize that through additional spring and damper tuning, improved performance could be achieved. By utilizing the trade study process and simulation tools, the impact of future tuning changes implemented to improve the half round event results can be assessed for all of the vehicle performance parameters.

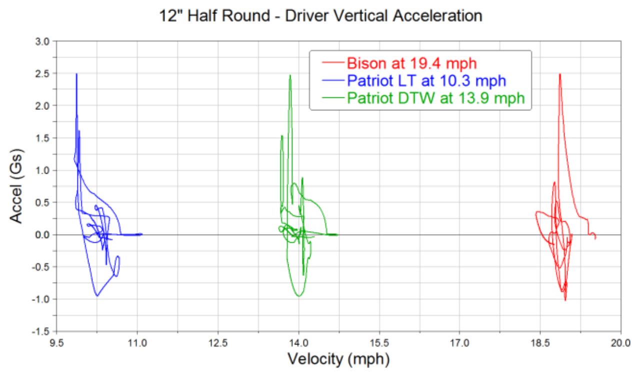

Figure 9: 2.5g Speed over 12" Half Round

Multiple vertical step climb heights were simulated based on the physical test operating procedure for standard obstacles TOP 2-2-611 [9]. Figure 10 shows the ADAMS model of the Patriot LT negotiating a step climb. The additional suspension travel on the Patriot DTW helps the concept climb a 36" vertical step while the Bison and Patriot LT climb a maximum height of 30".

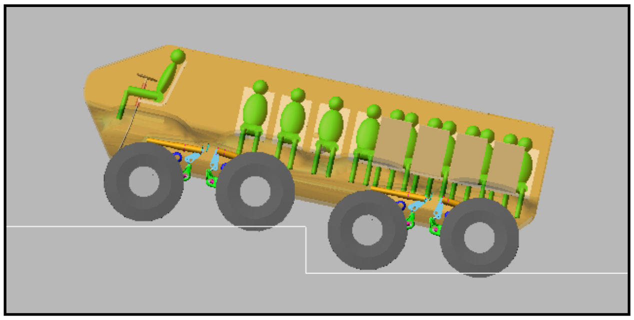

Figure 10: ADAMS Step Climb Event

The mobility simulation results for the three performance parameters chosen for this trade study example are shown in Table 14.

	Bison	**Patriot LT**	**Patriot DTW**
Static Stability Factor	0.69	0.77	0.87
2.5g Speed over 12" Half Round	19.4 MPH	10.3 MPH	13.9 MPH
Height of Vertical Step Climb	30"	30"	36"

Table 14: Mobility Simulation Results

Packaging

For this study, the primary packaging related parameters are center of gravity (CG) height, number of power packs, and number of power delivery paths. These design parameters were combined into full vehicle concepts and Parametric Technology's Pro/ENGINEER [10] computer aided design (CAD) software was used to develop the physical vehicle geometry.

There is not a direct requirement for CG height, but this becomes one of the primary competing attributes in the performance balance among force protection, vehicle mobility, and vehicle survivability. The development of the vehicle package directly impacts the CG height and is comprised of many considerations. Figure 11 below shows the rear view of the Patriot DTW CAD package. The package starts with the soldier and includes accommodation for a full range of soldier sizes and equipment plus head to roof clearance [11]. Working down, results from simulations are used to determine the travel needed in the blast attenuating seat and floor. Hull deflection and thickness was considered to understand how much clearance was required between the hull and the floor. The tire envelopes were created to represent the volume occupied by the tire through the full range of suspension travel and steer. The tire envelope comes closest to the hull when compressed into jounce and steered. The amount of jounce travel determines the relationship between the hull and the suspension heights. Less jounce travel can enable a lower CG height, but has a direct impact on the mobility performance of the concept. For this reason, jounce travel was identified as a primary design parameter and varied on the vehicle concepts.

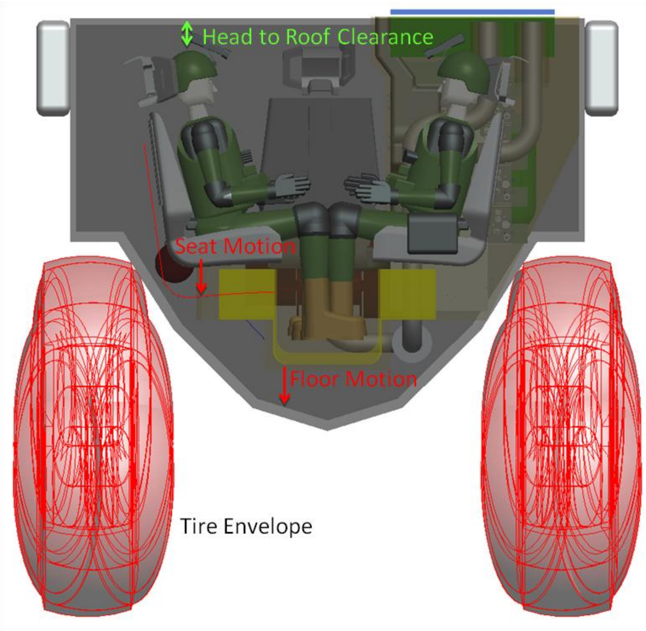

Figure 11: CAD Package of Vertical Stack-up

The number of power packs is simply the number of independent power pack sets in the vehicle. There are many factors to consider when incorporating multiple power packs, but for this study the redundancy offered was considered an enabler for post-event vehicle survivability. The Bison includes a single power pack while both Patriot concepts use two.

The number of power delivery paths is also intended to be a measure of the post-event vehicle survivability. While there are many potential blast event scenarios, this performance parameter was intended to consider the ability to move the vehicle after a blast event and identify the number of paths used to transfer motive power. With front and rear transfer case outputs supplying all of the power to the front and rear axle sets in the Bison concept, there are two power delivery paths. With wheel hub motors at each wheel station, the Patriot concepts each have eight power delivery paths.

	Bison	Patriot LT	Patriot DTW
Center of Gravity Height	68.5"	60.8"	60.8"
Number of power packs	1	2	2
Number of power delivery paths	2	8	8

Table 15: Packaging Results

The vehicle package was constantly iterated throughout the concept development process. By including the packaging work in the process, physical feasibility was verified and the design space for each concept refined.

TRADE STUDY RESULTS

The performance parameter results were compiled in the trade study format as shown in Figure 12 below. By maintaining the trade study in this simple format, the concepts can be compared using the data produced in the concept development process. The overall score can be used as a guide to select the leading concept based on the program objectives. Based on the simulation results and the assigned weighting, the Patriot DTW achieves the highest score and is the leading concept.

DFND Concept Performance Parameter Trade Matrix

		Concepts		
Performance Parameter	**Weighting**	**Bison**	**Patriot LT**	**Patriot DTW**
Az Center Blast	45%	0.21	0.69	0.69
Static Stability Factor	17%	0.29	0.58	0.91
2.5G Speed over 12" Half Round	9%	0.93	0.00	0.24
Height of Vertical Step Climb	9%	0.50	0.50	1.00
Number of Power Packs	10%	0.00	0.50	0.50
Number of Power Delivery Paths	10%	0.11	0.78	0.78
Total	100%	**0.281**	**0.585**	**0.706**

Figure 12: Trade Study Matrix

The trade study ranking data is also plotted as shown in Figure 13. This graph provides a visual representation of the concept for each performance parameter. Each concept is represented by a colored line as shown in the legend and a higher value for each parameter is better. This is a graphical method of showing that the Patriot DTW is the leading concept.

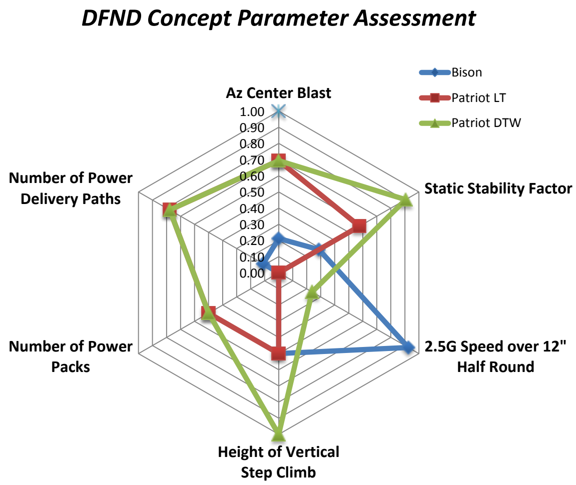

Figure 13: Graphical Parameter Assessment

CONCLUSION

The objectives of the DFND concept development program were to develop novel vehicle concepts to maximize force protection, vehicle mobility, and vehicle survivability. This paper described the systems engineering trade study process used to develop and rank vehicle concepts. Through blast simulation, mobility simulation, and vehicle packaging, the performance parameters for competing design parameters were established. The results of the simulations were included in the trade study. A weighting was applied corresponding with the program objectives and an overall concept rating was computed. The trade study results indicate that the Patriot DTW concept has the highest score. This trade study process can be expanded to include more performance parameters and used to guide the decision making process throughout the concept vehicle design cycle.

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